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Changes In Child Survival Are Strongly Associated With Changes In Malnutrition In Developing Countries

David L. Pelletier, PhD
Edward A. Frongillo, PhD

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Food and Nutrition Technical Assistance Project (FANTA)
Academy for Educational Development 1825 Connecticut Ave., NW Washington, DC 20009-5721
Tel: 202-884-8000 Fax: 202-884-8432 E-mail: fanta@aed.org Website: www.fantaproject.org

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Food and Nutrition Technical Assistance Project
Academy for Educational Development
1825 Connecticut Avenue, NW
Washington, D.C. 20009-5721
Tel: 202-884-8000
Fax: 202-884-8432
Email: fanta@aed.org
Website: www.fantaproject.org

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EXECUTIVE SUMMARY

Considerable evidence suggests that malnutrition affects human performance, health and survival, including physical growth, morbidity, mortality, cognitive development, reproduction, physical work capacity and risks for several adult-onset chronic diseases. In recent decades development agencies and governments have emphasized selective interventions to improve health and nutritional status, such as immunizations, oral rehydration, antibiotics, and micronutrients, with child survival being a major motivation and justification. Whereas the efficacy of these approaches for improving child survival has been amenable to study and has provided some of the rationale for using them, it has not been possible to directly test the effects of improvements in general malnutrition. The present study quantified the effects of changes in general malnutrition, as measured by child weight-for-age (WA), on changes in child survival in 59 developing countries, using aggregate, longitudinal data at national and sub-national levels from 1966 to 1996. Mixed model analysis (in SAS) was used, to take advantage of the multi-level and longitudinal nature of these data sets. Results reveal that changes in WA have a statistically significant effect on changes in child mortality, independent of socioeconomic and policy changes represented by the secular trend. The secular trend in mortality begins earlier and levels off at higher mortality rates in populations with a higher prevalence of malnutrition. It is concluded that gaps in coverage of selective interventions are more likely and more serious in the more malnourished populations. Continued reduction in mortality will require improved targeting of selective interventions and general nutritional improvement to the most marginal populations.

INTRODUCTION

The effects of malnutrition on human performance, health and survival has been the subject of extensive research for several decades. Although many questions remain concerning the precise mechanisms and magnitude of effects, there is now considerable evidence that malnutrition has effects on physical growth, morbidity, mortality, cognitive development, reproduction, physical work capacity and risks for several adult-onset chronic diseases[1]. The increased salience of nutrition as a central concern for social and economic development is further revealed by the awarding of two Nobel Prizes in economics for nutrition-related work in recent years (Richard Fogel and Amartya Sen) and the prominence of food security and nutrition in international discourse related to human rights[2], human development[3], health[4], and national development[5].

Despite this apparent agreement at a scientific and general policy level concerning the importance of nutrition as a development concern, a number of scientific and policy questions remain concerning the most effective and appropriate policies and programs for improving population nutritional status and preventing its adverse consequences. One of the enduring questions relates to the most appropriate mix of selective health and nutrition interventions versus broader-based improvements in population nutritional status. Since the early 1980's selective health and nutrition interventions have become a major component of the policy portfolios of international agencies, national governments and non-governmental organizations. Two examples are the GOBI interventions promoted by UNICEF and WHO in the 1980's (Growth monitoring, Oral rehydration, Breastfeeding and Immunizations), and micronutrient interventions promoted by many international agencies in the 1990's. In both cases there has been extensive scientific evidence for the efficacy and potential effectiveness of these interventions for improving child survival and other important outcomes[6].

Among all the developmental outcomes noted above, child survival has remained a powerful rationale and motivator for international agencies. Thus, in terms of the overall direction of policies, in recent decades the notion that the improvements in the overall nutritional status of a population should be a major policy goal because of the multiple long-term and short-term impacts on human and economic development, and because of its equity implications, has given

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[1] R.D. Semba and M.W. Bloem (eds), *Nutrition and Health in Developing Countries* (Totawa Press: Humana Press, 2001). Also see R. Martorell and F. Haschke (eds), *Nutrition and Growth* [Nestle Nutrition Workshop Series, Pediatric Program, vol 47] (Phila, PA: Lippincott, Williams and Wilkins, 2001).

[2] See ACC/SCN, "Adequate Food: A Human Right," SCN News (Geneva, Switzerland: Administrative Coordinating Committee, Subcommittee on Nutrition, 2001).

[3] See UNDP, *Human Development Report* (New York: Oxford University Press, 1996).

[4] See World Bank, *Investing in Health: World Development Report* (Oxford: Oxford University Press, 1993).

[5] See World Bank, *Attacking Poverty: World Development Report* (Oxford: Oxford University Press, 2001).

[6] R. Cash, G. Keusch, and J. Lamstein (eds), *Child Health and Survival: The UNICEF GOBI-FFF Program.* (London: Croom Helm Ltd,1987). See also K. Hill, *Child Health Priorities for the 1990': Report of a seminar held June 20-22, 1991 at the Johns Hopkins University School of Hygiene and Public Health* (Baltimore, MD, 1992); G.H. Beaton et al., *Effectiveness of vitamin A supplementation in the control of young child morbidity and mortality in developing countries* (Geneva, Switzerland: Administrative Coordinating Committee, Subcommittee on Nutrition Nutrition Policy Discussion Paper No. 13, 1993); ACC/SCN, *Third Report on the World Nutrition Situation* (Geneva, Switzerland: Administrative Coordinating Committee, Subcommittee on Nutrition, 1997).

way to a more narrow focus on child survival as a dominant policy goal. Moreover, there has been a further narrowing of the focus onto micronutrient and other selective health interventions as dominant strategies.

The purpose of the present paper was to examine the implications of this policy shift as it relates to the single outcome of young child survival. Specifically, the purpose was to examine the relationship between changes in child and under-5 mortality rates in developing countries in the past two or three decades and changes in the general nutritional status of children during the same period. In general this period has been characterized by substantial declines in infant and child mortality rates, reflecting a host of social, economic and policy changes, but these changes have occurred at different rates and to varying degrees across world regions, countries and sub-national units. This study sought to estimate the effects of changes in child malnutrition versus the effects of all other social, economic and policy changes (combined) by employing statistical models that fully exploit the covariation between geographic and temporal variations in mortality rates and malnutrition rates. This differs from our earlier work on these relationships[7] by using population-level (rather than child-level) estimates of mortality and malnutrition, by examining dynamic relationships (changes in malnutrition and changes in mortality), and by using a much larger set of developing countries (59 versus 8) to permit greater generalizability.

METHODS

Research Strategy

This study was based on analysis of aggregate-level data on young child mortality and malnutrition in all developing countries for which suitable data are available at two or more points in time. Two data sets were constructed for this purpose, one representing national-level aggregates and the other representing sub-national aggregates (hereafter called "provinces" for convenience), and parallel analyses were undertaken with each data set. The national data set offers broader geographic coverage (59 countries) and greater temporal variation (extending into the 1970's for many countries). The sub-national data set has fewer countries[8] and less temporal variation (extending back to 1986), but it contains a larger number of analytical units (99 provinces) and potentially greater variation in levels and trends for malnutrition and mortality across these units. The statistical models described below permit an analysis of the relationship between malnutrition and mortality at country level (and, in the sub-national analysis, at the provincial level as well) after statistically adjusting for all unmeasured factors operating at country level. These include social and economic factors like levels of income and education, as well as curative health services, public health infrastructure and any new child survival programs such as oral rehydration, immunization, antibiotics or vitamin A supplementation. The statistical models control for the *status* of these unmeasured factors at one point in time as well as the *changes* in these factors over time, thereby permitting an estimate of the effect of changes in malnutrition on changes in mortality that is statistically independent of these broader,

[7] D.L. Pelletier, E.A. Frongillo, D.G. Schroeder, and J.P. Habicht, "A methodology for estimating the contribution of malnutrition to child mortality in developing countries." J Nutr 124:2106S-2122S (1994).
[8] F.M. LaForce et al., *A Better Future for Children: Progress Toward World Summit Goals for Health and Nutrition* (BASICS II Project for USAID: Arlington, VA, 2001).

unmeasured changes. To the extent that malnutrition rates themselves have been influenced by these unmeasured factors, which indeed is likely, the effect of malnutrition presented here are likely to be conservative estimates of the actual effects.

National Data Set

The national longitudinal data sets were created by merging child and infant weight for age from the WHO Global Database on Child Growth and Malnutrition[9] with child mortality, infant mortality and under-5 mortality from the World Development Reports[10]. The data were matched on a national survey basis, not on the individual level.

The WHO Global Database on Child Growth and Malnutrition was compiled data from articles, government health statistics, survey reports and national surveillance systems[11]. Weight-for-age is compared to NCHS/WHO international reference population (NCHS/WHO, 1983), and the percent of children below - 2 Z-scores was used in the present study. Criteria for inclusion in this study were that the weight-for-age data came from a national survey and the age range included 0 to 4.99 years. Several data records had age ranges that exceeded the maximum age but were still included: Bangladesh 1992 (0.5 to 5.99 years of age), Bhutan 1987 (0 to 5.99 years of age), Chile 1984, 1985 and 1996 (0 to 5.99 years of age), Costa Rica 1989, 1990, 1991, 1992, 1993 (0 to 5.99 years of age) and 1996 (0.25 to 6.99 years of age), Honduras 1996 (1 to 4.99 years of age), Nicaragua 1981 (0 to 5.99 years of age), Nigeria 1993 (0.5 to 5.99 years of age), Peru 1975 and 1984 (0 to 5.99 years of age), Philippines 1982 (0 to 5.99 years of age), Singapore 1973/1974 (0 to 5.99 years of age) and Uruguay 1987 (0 to 5.99 years of age).

The mortality data of World Development Reports and World Development Indicators were compiled from a variety of sources: the UN Demographic Yearbook and Population and Vital Statistics Report; UN Infant Mortality: Early Estimates and Projections, 1950-2025; Population Bulletin of the United Nations, 1982-; the World Bank itself; and life table estimates[12]. The UN Demographic Yearbook received its data from mortality registries of each country, census data, demographic surveys of households, and "other sources and general estimates"[13] depending on which sources of information were available and deemed to be most reliable. The quality and suitability of various demographic data for the purposes of the present study were ascertained by consulting with experts at Cornell University (Ithaca, NY), the Statistics Division of the UN Secretariat (New York, NY), the Population Reference Bureau (Washington, DC), PAHO (Washington, DC) and the Population Council (Washington, DC).

The World Development Reports present infant and child mortality data up to 1987. From 1988 to 1989 they only reported infant mortality. After 1989, infant and under-5 mortality were reported. In order to allow for the analysis of child and under-5 mortality, we calculated the missing mortality based on a formula provided by Macro International Inc., which conducts the

[9] World Health Organization/Department of Nutrition for Health and Development, *WHO Global Database on Child Growth and Malnutrition* (WHO Program of Nutrition: Geneva 1997). See also, World Health Organization/Department of Nutrition for Health and Development, *WHO Global Database on Child Growth and Malnutrition (2001);* available from http://www.who.int/nutgrowthdb/. Accessed August 15, 2002.
[10] World Bank, *World Development Report* (New York: Oxford University Press, 1978-1998/99).
[11] WHO (1997) Ibid.
[12] World Bank (1978-1998/99) Ibid.
[13] *UN Statistical Yearbook* (UN Statistics Division,1992).

Demographic and Health Surveys: *(1 - Infant Mortality) x (1 – Child Mortality)*^{4} *= (1 – Under5 Mortality).* This cohort-based formula differs somewhat from the more simplified version (in which Under 5 mortality is simply the weighted average of the infant and child mortality, with the latter weighted four times the former), but the difference between these two calculations is negligible.

The primary dependent variable used in this study was child mortality (1-4.99 years). This choice was based on the fact that a high proportion of infant deaths occur in the neonatal period (less than one month) and are unrelated to the infant's postnatal nutritional experience. Moreover, many of the national nutrition surveys do not measure infants less than 2-3 months of age. Thus, the use of child mortality as an outcome permits a more accurate match between the age range for the mortality data and the age range for the weight-for-age data. That said, under-5 mortality (0-4.99 years) is the indicator most commonly used for policy purposes and there is policy interest in its relationship to nutritional status. Thus, a parallel set of analyses is presented for under-5 mortality in Appendix 2.

Merging of the malnutrition and mortality from the two data sources was conducted according to the year of measurement, with a tolerance of plus or minus 3 years in most cases. Mortality data in the World Development Reports consistently predated the publication date by 2 years. Thus, a report published in 1996 would provide mortality data from 1994. In the final national longitudinal data set, 5 out of 59 cases have a two-year difference between measurement of malnutrition and mortality, with all others being less than two years. In nine cases there was a very short interval between anthropometric surveys (three years or less) and a precise year-of-match with mortality was not available. In those cases the mortality was estimated by linear interpolation from the closest available years.

Sub-national Data Set

The creation of a sub-national data set was simplified in some respects because the major source for these data (final reports from the Demographic Health Surveys) contain estimates of low weight-for-age as well as child and under-5 mortality (Macro International Inc., Calverton, Maryland, USA). All publications available in current print as of August 2000 were located and used in the initial data set. In order to be included, surveys had to have data on child and under-5 mortality and the prevalence of low weight-for-age for at least 3 provinces (or comparable sub-national units). The temporal proximity of the malnutrition and mortality data was assured in most cases by the fact that they both derived from the same survey.

Some surveys showed inconsistencies or data gaps between countries or between waves within the same country. In two cases (Philippines 1993, Bangladesh 1994) the DHS surveys did not contain data on weight-for-age, but data from the WHO Global Database were available and used. In several other cases (Dominican Republic 1986, 1991 and 1996, Nicaragua 1998, Ghana 1988, 1993 and 1998, Madagascar 1992 and 1997, Zambia 1992 and 1996, Tanzania 1996, 1991/1992) provinces or districts were consolidated to permit comparison across time.

DATA ANALYSIS

In each data set, national and sub-national, a separate record was created for the malnutrition and mortality observed in a given year for a given country or province. Thus, a country with data at four points in time would be represented by four records. As shown in Table 1, the national data set contains 59 countries and a total of 182 observations, with each country having data for at least two points in time. The sub-national data set contains 19 countries, 99 provinces and 220 observations, again with each province having data for at least two points in time. In the national data set the mean interval between adjacent surveys is 4.3 years while the mean interval between first and last survey in a given country is 11.2 years. In the sub-national data set most countries have only two surveys and the mean interval between them is 4.9 years, with all surveys taking place after 1985.

Table 1: Structure of the National and Sub-National Longitudinal Data Sets[14]

	Sub-Saharan Africa	Central/South America	Asia/North Africa	All Countries
NATIONAL DATA SET				
No. of countries	21	18	20	59
No. of surveys (data points)	46	75	61	182
Survey intervals (years) [15]	4.7 (2.8)	3.5 (2.7)	4.4 (2.4)	4.3 (2.6)
Years between first/last survey	9.4 (4.8)	14.7 (7.3)	10.2 (6.3)	11.2 (6.5)
Range of survey years	1976-96	1966-96	1975-98	1966-98
SUB-NATIONAL DATA SET				
No. of countries	10	5	4	19
No. of Provinces	57	24	18	99
No. of surveys (data points)	122	57	41	220
Survey intervals (years) [15]	5.4 (.64)	5.1 (1.6)	3.6 (.88)	4.9 (1.0)
Range of survey years	1986-98	1986-98	1987-98	1986-98

In addition to the prevalence of low weight-for-age, child mortality and under-5 mortality, each record contains the following variables: country, province (in the sub-national data set), world region and year of measurement. Derived variables included the natural logarithms (ln) of the mortality variables, a variable for "year" and the quadratic (squared) value of year. ("Year" is defined by initializing to 1966 in the national data set, and to 1986 in the sub-national data set). Preliminary analyses with the national data set included five regions: Sub-Saharan Africa (21 countries), Central/South America & Caribbean (18 countries), South Asia (4 countries), Southeast Asia (7 countries) and West Asia/North Africa (9 countries). Although there was interest in examining possible differences among the latter three regions, they were collapsed into a single group ("Asia/North Africa") in the later analyses, out of a concern for sample sizes. The sub-national analyses used these same three regions, although that data set contains only a

[14] Values are mean and SD, unless otherwise noted.
[15] Refers to the interval between adjacent surveys in a given country or province.

sub-set of countries (N=19) in the national data set (N=59). The list of countries in each region is included in Appendix 1.

All data analysis was conducted with the SAS System (version 6.12 and 8.1) from the SAS Institute Inc., while residual and leverage plots were created with SPSS for Windows (version 10.0), SPSS Inc. Mixed model analysis (PROC MIXED, in SAS) was used in order to take advantage of the multi-level and longitudinal nature of these data sets. Mixed models contain both fixed and random effects and adjust for the correlation among analytical units (such as provinces) within a larger analytical unit (such as country). When applied to longitudinal data such as these, mixed models also adjust for the unmeasured factors present in a given analytical unit (such as a province), thereby permitting each unit to act as its own pseudo-control when examining the relationship between changes in malnutrition and changes in mortality over time. Correlations across analytical units in a multi-level data set are due to shared underlying factors such as similar socioeconomic conditions, access to health care, public health infrastructure and child survival programs. This analysis technique permits an examination of relationships between the variables of interest, such as malnutrition and mortality, without disturbance by correlation due to common underlying factors within a country or province[16]. In the present case this was achieved by defining country (and province, in the sub-national analysis) as a random factor in the mixed model, and by simultaneously controlling for (initialized) year.

Model development was guided by several key research questions. First, is there a relationship between changes in general malnutrition (as measured by prevalence of low weight-for-age - WA) over the past several decades and changes in young child mortality? Second, are these relationships evident after controlling for unmeasured factors at country or province level and for the secular decline in mortality due to changes in factors other than general malnutrition? These "other factors" are modeled by including a term for Year, along with random factor terms for Country (in the national analysis) and Country and Province (in the sub-national analysis). Third, do these relationships vary across world regions and over time? This question is examined by testing the significance of two-way and three-way interaction terms involving WA. Year and Region, while still controlling for Country (and Province, in the sub-national analysis). Probability values of .05 are accepted as statistically significant for main effects and values of .10 are accepted as significant for interaction terms.

In all cases, these questions were examined in relation to child mortality and under-5 mortality, and these have been modeled in the log scale. The log scale is appropriate in this case for two theoretical reasons. First, earlier work has revealed that when child mortality is regressed on child malnutrition the slope depends upon the absolute level of morbidity (and mortality) in the population[17]. Second, the secular decline in mortality is known from historical experience to approach zero asymptotically, and this can be modeled most efficiently by using the log of mortality. Both of these theoretical rationales were tested and found to hold in the present data.

[16] C.L. Arnold, "Methods, plainly speaking; An introduction to hierarchical linear models," Measurements and Evaluation in Counseling and Development 25: 58-90 (1992).
[17] D.L. Pelletier, E.A. Frongillo, and J.P. Habicht, "Epidemiologic evidence for a potentiating effect of malnutrition on child mortality." Am J Publ Hlth 83:1130-33 (1993).

RESULTS

Child mortality for all countries combined declined by a mean of 4.0 deaths per thousand per year in the national data set and 3.1 in the sub-national data (Table 2). The inter-country variation around these means, as measured by the standard deviations, is 7.7 at the national and 3.9 at the sub-national levels. These standard deviations for the mortality and WA variables in the two data sets are of particular interest because they relate directly to the power of the present study to detect significant relationships. Under-5 mortality declined by a larger amount in absolute terms (-33.7 and -20.0, respectively) but is of similar magnitude in relative terms (roughly 20-30%). Child malnutrition declined by an average of 3.8 percentage points in the national data set and remained virtually unchanged, on average, in the sub-national data set. The standard deviation for WA change is 7.7 and 5.6 percentage points, respectively. The most notable differences across the three regions is that Sub-Saharan Africa had higher levels of malnutrition and mortality, and experienced less improvement over time in absolute terms and in relative terms (Figures 1-3). These temporal relationships are based on quadratic equations applied within each region to obtain predicted values at the three specified years.

Table 2: Descriptive Statistics for the National and Sub-National Longitudinal Data Sets[18]

Variable	Sub-Saharan Africa	Central/ South America	Asia/ North Africa	All Countries
NATIONAL DATA SET				
Child mortality (per 1000 per yr)	18.6 (9.1)	4.6 (5.5)	6.5 (7.1)	8.6 (9.2)
Change in child mortality [19]	-2.1 (8.6)	-4.6 (6.1)	-5.2 (8.0)	-4.0 (7.7)
Under-5 mortality (per 1000)	163.0 (64.9)	64.1 (47.5)	83.2 (56.0)	95.5 (68.0)
Change in Under-5 mortality [19]	-18.7 (39.3)	-45.5 (43.3)	-37.6 (40.5)	-33.7 (41.8)
Child malnutrition (pct < -2 Z-scores)	27.8 (9.3)	10.7 (7.7)	33.0 (18.8)	22.4 (16.0)
Change in child malnutrition [19]	1.2 (8.4)	-5.5 (4.7)	-7.2 (6.8)	-3.8 (7.7)
SUB-NATIONAL DATA SET				
Child mortality (per 1000 per yr)	21.9 (13.9)	6.4 (4.2)	7.2 (4.7)	15.1 (13.1)
Change in child mortality [19]	-3.0 (5.0)	-3.7 (3.0)	-2.8 (2.2)	-3.1 (3.9)
Under-5 mortality (per 1000)	163.8 (67.7)	80.6 (34.9)	96.9 (37.9)	129.8 (67.7)
Change in Under-5 mortality [19]	-13.0 (21.8)	-29.7 (24.0)	-25.6 (12.5	-20.0 (21.3)
Child malnutrition (pct < -2 Z-scores)	27.7 (9.9)	15.4 (10.6)	19.4 (18.5)	22.8 (13.2)
Change in child malnutrition [19]	+2.3 (5.5)	-2.3 (6.1)	-2.4 (3.5)	-.12 (5.6)

[18] Values refer to mean and SD.
[19] Refers to the change between the first and last surveys in each country.

Table 3: Results of Mixed Model Regression, Natural Log of Child Mortality at National Level (longitudinal)[20]

Variables	Region	Model							
		1	2	3	4	5	6	7	8
Intercept		3.065	.580	2.195	1.749	1.570	2.308	2.839	2.319
Year		-0.0582***		-0.0488***	-0.0501***	-0.0401***	-0.0785***	-0.0927***	-0.0682 p=.001
WA			0.0453***	0.0264***	0.0248***	0.02265***	0.001175	-0.00527***	0.00647 p=.437
Region	SSAfrica SCAmerica Asia/NAfr				1.503 -0.0310 0 ***	1.0767 0.5804 0 ***	1.0138 0.7213 0 ***	.5124 -0.2783 0	1.0138 0.7213 0 p=.663
Year x Region	SSAfrica SCAmerica Asia/NAfr					0.0172 -0.0287 0 ***		0.0380 0.0062 0 ***	0.0148 -0.0457 0 p=.174
Region x WA	SSAfrica SCAmerica Asia/NAfr								-0.0110 -0.0486 0 p=.238
Year x WA							0.001216***	0.00125***	0.00062 p=.008
Year x Region x WA									0.00057 0.00285 0 p=.045
Country Variance		1.356	.913	1.015	0.519	0.534	0.520	0.543	0.542
Residual		0.185	0.286	0.190	0.189	0.173	0.172	0.164	0.161
n		182	182	182	182	182	182	182	182

[20] Values are regression coefficients unless as noted. Overall term (F-test): *** p<.01 **p<.05 *p<.10 Intercept only model Variance=1.272, residual= 0.336

The natural log of child mortality has decreased significantly over time (Model 1, Table 3) and is also positively and significantly associated with changes in WA (Model 2). Both of these relationships remained statistically significant after controlling for the other variable and unmeasured factors at country level (Model 3). WA remained highly significant and of very similar magnitude even after controlling for regional differences in levels of mortality (Model 4). There are highly significant two-way interactions between Year x Region (Model 5) and Year x WA (Model 6). These two-way interactions suggest that the pace of mortality decline varies across regions (being slowest in SS Africa) and across populations that differ in the prevalence of malnutrition (being slowest in populations with a high prevalence). These two interactions remained significant even in the presence of each other (Model 7), suggesting that the slow mortality decline in SS Africa was not simply due to its high prevalence of malnutrition. Finally, there is a statistically significant three-way interaction among Year, WA and Region (Model 8). Note that many of the individual variables and two-way interactions are not significant in Model 8, but it was necessary and appropriate to retain them in this final model in order to interpret the directions and slopes of the relationships implied by this model.

The relationships implied by Model 8, including the three-way interaction, are illustrated visually in Figures 4-6 and numerically in Table 4, with the ranges for Year and Malnutrition prevalence chosen to include most of the data points in each region. The following patterns are revealed:

1) child mortality was highest among the regions in SS Africa at any given period or level of malnutrition;

2) the secular decline in child mortality, at a given level of malnutrition, has been greater in Sub-Saharan Africa in terms of *the absolute* numbers of deaths (e.g., it decreased from 18.4 in 1980 to 14.2 in 1995 for WA=30, which is greater than the decrease in other regions). However, at a malnutrition prevalence of 30% *the annual rate* of decline in SS Africa has been only 1.7%, which is similar to the 1.0% seen in CS America (which began the period with far lower child mortality rates) and far lower than that seen in Asia/N Africa (5.1%);

3) the secular decline in mortality has been greater, in absolute terms and in relative terms, in populations with lower levels of malnutrition (i.e., when the prevalence of low WA is 10% versus 30%); this was seen in all three regions but less markedly so in the Asia/NAfrica group of countries;

4) in all three regions the statistical effect of changes in malnutrition on changes in mortality was greater in 1995 than it was in 1980; specifically, across the three regions in 1980 child mortality changed by roughly 1.0 to 1.6% (compounded) for each percentage point change in the prevalence of low WA. In 1995 child mortality changed by 2.5% (compounded) for each percentage point change in malnutrition prevalence in Asia/N Africa, 3.2% in SS Africa and 6.4% in CS America. Thus, despite marked reductions in mortality from 1980 to 1995 these results suggest that the population-level association between general malnutrition and child mortality was stronger in more recent years.

Table 4: Predicted Values of Child Mortality for Selected Years and Malnutrition Prevalences, by Region. (from Model 8, Table 3)

		Child Mortality		
Region	**Year**	**WA=10**[21]	**WA=30**[21]	**WA Rate** [22]
Africa	1980	13.8	18.4	**1.3%**
	1995	7.4	14.2	**3.2%**
	Year Rate [23]	**-4.2%**	**-1.7%**	**-**
C/S America	1980	3.9	5.1	**1.0%**
	1995	1.2	4.4	**6.4%**
	Year Rate	**-8.2%**	**-1.0%**	**-**
Asia/ N Africa	1980	4.0	5.6	**1.6%**
	1995	1.3	2.7	**2.5%**
	Year Rate	**-6.4%**	**-5.1%**	**-**

The sub-national results in Table 5 confirm the national findings with respect to Models 1-5. However, Year x Region is the only significant interaction in the sub-national data set. Neither of the two-way interactions involving WA (i.e. Region x WA and Year x WA) was statistically significant, nor was the three-way interaction (Year x Region x WA). This is in contrast to the results at the national level. It is relevant to note from Tables 1 and 2 that the sub-national data set has a much small interval between first and last surveys in each country than does the national data set (4.9 versus 11.2 years), is restricted to the years 1986-98, and has a much smaller change in malnutrition prevalence (-0.12 versus –3.7 prevalence points). While these considerations may limit the power to detect interactions, it is relevant to note that the magnitude of the WA coefficients are highly similar to those found at the national level (e.g., 0.0292 in Model 3, compared to 0.0264 in Model 3 at the national level).

[21] Values are child deaths per 1000 children per year.
[22] Values are the compounded rate of change in mortality as a function of malnutrition (WA Rate).
[23] Values are the compounded rate of change in mortality as a function of year (Year Rate).

Table 5: Results of Mixed Model Regression, Natural Log of Child Mortality at Sub-national Level (longitudinal)[24]

		Model				
Variables	**Region**	**1**	**2**	**3**	**4**	**5**
Intercept		2.6885	1.585	2.007	1.444	1.544
Year		-0.0458***		-0.0432***	-0.0436***	-0.0489***
WA			0.0336***	0.0292***	0.0277*	0.0247***
Region	SSAfrica SCAmerica Asia/NAfr				1.099 0.0721 0 ***	0.9851 0.1314 0 ***
Year x Region	SSAfrica SCAmerica Asia/NAfr					0.0172 -0.0118 0 **
Region x WA	SSAfrica SCAmerica Asia/NAfr					
Year x WA						
Year x Region x WA						
Country Variance		0.452	0.734	0.467	0.202	0.207
Province Variance		0.071	0.141	0.092	0.094	0.099
Residual		0.094	0.063	0.055	0.054	0.051
n		226	226	226	226	226

The results for under-5 mortality were largely in line with those for child mortality and, for ease of presentation, are shown in Tables A1 to A3 of Appendix 2. As with child mortality, the best-fitting model at the national level was the full model that included a three-way interaction term. The direction, magnitude and interpretation of these interactions parallels the patterns found for child mortality, although the absolute levels of mortality were much higher as expected. At the sub-national level, the interaction results also were highly similar to those for child mortality.

[24] Values are regression coefficients unless otherwise noted. Overall term (F-test): *** p<.01 **p<.05 *p<.10
Intercept only model: Country Variance=0.8832, Province Variance= 0.1000, Residual=0.0771

DISCUSSION

The central purpose of this study was examine the relationship between changes in young child mortality in developing countries in recent decades and changes in the general nutritional status of children during the same period. In particular, the purpose was to determine the extent to which changes in general malnutrition may have had a significant effect independent of other social, economic and policy changes occurring during this period, including but not limited to the greatly expanded coverage of immunizations, oral rehydration, antibiotics, vitamin A supplements and other selective health and nutrition interventions. It is noteworthy that the efficacy and effectiveness of selective interventions can be, and have been, evaluated and documented through short-term experimental designs and evaluations of intervention projects. However, it is much more difficult to conduct studies of how changes in general malnutrition may affect young child survival because such studies would require long durations and large sample sizes, and they confront a host of potential confounding factors and ethical dilemmas. Although the observational nature of this study did not provide the firm basis for causal inferences provided by experimental studies, the present study may represent the most feasible approach for examining these relationships.

The results presented here suggest the following conclusions: 1) changes in young child mortality over the past several decades were significantly related to changes in general malnutrition; 2) these statistically significant relationships exist seen even after controlling for the substantial secular declines taking place as a result of other social, economic and health-related factors (including expanded coverage of the selective interventions noted above); and 3) the pace of change in mortality has differed across world regions and the strength of the association with malnutrition has differed over time.

With respect to the latter conclusion, this study specifically revealed that: a) in all three regions the pace of mortality change has been significantly slower in the more malnourished populations; b) in all three regions the association with malnutrition (in terms of the percentage reduction in mortality) has become stronger over time; and c) considering its very high child mortality rates, the annual rate of mortality change in SS Africa was very slow (i.e., about 1.7% which is comparable to that seen in CS America after it had already reduced its child mortality to very low levels).

The methodology of this study had several strengths and weaknesses that should be taken into account. Its strengths included its diverse geographic coverage, the longitudinal nature of the data and the analysis, and the use of multi-level statistical models to adjust for unmeasured factors at national and sub-national levels. These latter two points, in particular, are critical for distinguishing this study from other cross-national or “ecological” studies. Such studies typically involve cross-sectional data and are severely limited in their ability to control for potential confounding factors. They also are subject to the ecological fallacy of assuming that the relationships observed among population aggregates can be applied to individuals or households[25]. In the present case, the longitudinal data and use of multi-level models did not eliminated the ecological nature of the data but did provide a much stronger method to adjust for unmeasured national or sub-national factors that may affect mortality through pathways that are

[25] W.S. Robinson, “Ecological correlations and the behavior of individuals,” Am Sociol Rev 15:351-357 (1950).

separate from malnutrition or that are mediated by malnutrition. In effect, each country or province served as its own pseudo-control when estimating the relationship between changes in malnutrition and changes in mortality, thereby eliminating the need for direct measurement of "fixed factors" that would confound the interpretation in a cross-sectional analysis. Moreover, it did so without confronting the problem of residual bias (arising from imprecise measurement of confounding factors) that complicates the use of more direct measures of confounding factors in multiple regression models.

As regards the ecological fallacy, it is relevant to note that no attempt was being made here to apply the coefficients from the current findings to individual children. The associations at the individual level have been estimated in earlier work[26] and are not influenced by the present findings. The present study used mortality rates and malnutrition prevalences as population-level attributes, not as proxies for individual-level attributes. It was undertaken precisely to understand the relationships at the population level and should be interpreted only in that context.

A potential weakness of the present method for controlling for unmeasured factors was that the statistical effect of general malnutrition may have been underestimated if changes in the unmeasured factors at country or province level were highly correlated with changes in malnutrition and/or if their effects were partially mediated through malnutrition. Such underestimation seems likely, but to an unknown extent, given that long-term changes in child care, child feeding, water, sanitation and health care are likely to be correlated with and partially mediated by changes in malnutrition.

Another limitation of this method is that it did not shed light on the *specific* nature of the other determinants of mortality (e.g., expanded coverage of oral rehydration therapy, immunization, vitamin A supplementation, and so on), the strength of their individual relationships to population mortality, nor the ways in which they might interact with general malnutrition in statistical models predicting mortality at the population level. Such interactions may be very important for policy purposes but were beyond the scope of the present study to elucidate. Given the method of control employed here (mixed models) it is likely that such interactions were incorporated into the residual variance estimates in the present models, but cannot account for the strong effects of general malnutrition reported here.

POLICY IMPLICATIONS

These findings have implications for understanding how the secular decline in mortality has occurred in the past, as well as how it may occur in the future. There are some indications from this study that the past and the future may be different in some important respects.

The period under consideration in this study has been characterized by substantial declines in young child mortality rates. As shown in Figures 1-3, for the countries included in this study child mortality declined by 39% in Sub-Saharan Africa, 78% in South/Central America and 80%

[26] D.L. Pelletier, E.A. Frongillo, D.G. Schroeder, and J.P. Habicht, "A methodology for estimating the contribution of malnutrition to child mortality in developing countries," J Nutr 124:2106S-2122S (1994).

in Asia/North Africa between 1975 and 1995. The corresponding figures for under-5 mortality are 32%, 63% and 60%, respectively. These were paralleled by marked reductions in malnutrition in South/Central America and Asia/North Africa, both with 60% reductions, but the Sub-Saharan African countries in this sample experienced a 12% *increase* in malnutrition during this period. The fact that Sub-Saharan Africa countries experienced a marked reduction in mortality despite showing no improvement in general nutritional status probably reflects the impacts of expanded coverage of immunizations, ORS, antibiotics, vitamin A capsules and other child survival interventions that have occurred in this and other regions during this period[27].

Some of the statistical parameters from these data can be used to estimate the quantitative contribution of improvements in general nutritional status to these marked declines in mortality, as well as to estimate the potential impacts of future improvements. Using a common WA coefficient for all three regions, as described in Appendix 3, it is estimated that 16% of the observed decline in child mortality in South/Central America from 1975-1995, and 27% of the decline in Asia/North Africa, is statistically attributable to *the statistically independent* effect of general malnutrition. In the Sub-Saharan Africa sample these calculations suggest that the 12% *increase* in malnutrition restrained the rate of mortality decline, such that the child mortality decline over this period could have been 67% rather than 39% if malnutrition in Sub-Saharan Africa had been *reduced* at the rate seen in the other two regions (by 60%). As noted, these are likely to be conservative estimates of the actual effects because of the correlation between the changes in the WA indicator and changes in other factors associated with child mortality.

The above calculations differ in several ways from the estimate of population attributable risk (PAR) reported earlier[28]. It should be noted that the PAR estimate is a function of: 1) the relative risk of mortality for individual children at various points below 90% of the reference median weight-for-age; and 2) the prevalence of children below 90% WA. It compares the then-current mortality to what would have been expected if all children were at or above 90% WA and it attributes all of the excess risk to malnutrition. By contrast, the above calculations are based on: 1) dynamic relationships (i.e., between *changes* in malnutrition and *changes* in mortality); 2) population-level relationships rather than individual-level; 3) *actual* changes in malnutrition during the study period rather than complete elimination of malnutrition; 4) a period of time when the coverage of selective health and nutrition interventions was much higher; and 5) regression coefficients that are conservative because they attribute most of the secular decline in mortality to changes in factors other than malnutrition (via the Year term in the models), despite the fact that some of their effects on mortality may be mediated by changes in malnutrition. Thus, the present calculations have different methodological and conceptual underpinnings and are not intended to be directly comparable to PAR estimates from previous work.

While the above estimates of the effect of malnutrition refer to the trends in the past, there are indications from this study that malnutrition may play an even more important role in the future. Two features of Table 4 and Figures 4-6 are relevant in this regard. First is the finding that the

[27] World Bank, *Investing in Health: World Development Report* (Oxford: Oxford University Press, 1993). See also, F.M. LaForce et al., *A Better Future for Children: Progress Toward World Summit Goals for Health and Nutrition* (BASICS II Project for USAID: Arlington, VA, 2001); and J.B. Mason et al., *The Micronutrient Report: Current Progress and Trends in the Control of Vitamin A, Iodine and Iron Deficiency* (Ottawa, Canada: The Micronutrient Initiative, 2001).
[28] D.L. Pelletier, E.A. Frongillo, D.G. Schroeder, and J.P. Habicht, "The effects of malnutrition on child mortality in developing countries," Bull WHO 73(4): 443-448 (1995).

annual rate of mortality decline has been significantly greater in populations with less malnutrition (i.e., prevalence=10%) than in those with more malnutrition (prevalence=30%). This is seen in all three regions. Second is the finding that the rate of mortality decline per unit change in malnutrition has become greater over time. This also is seen in all three regions. Given that both of these rates are calculated on a *compounded* basis, these differences can become quite large in absolute terms beyond 1995.

The increasing strength of the malnutrition effect over time is particularly noteworthy. As shown in Table 4, the results suggests that child mortality decreased at a compounded rate of 1.0 to 1.6% in various regions in 1980 for each prevalence point reduction in malnutrition, and the corresponding figures were 2.5% to 6.4% in 1995. Using the common WA coefficient for all regions combined described in Appendix 3, the overall compounded rate was 3.2% in 1995 and is predicted to be 4.1% in 2000 and 5.3% in 2005. The corresponding figure for under-5 mortality was 1.5% in 1995 and is predicted to be 2.0% in 2000 and 2.5% in 2005. The net effect of these differences is that the rate of the secular mortality decline is predicted to be lower in more malnourished populations and, simultaneously, the mortality ratio between the more malnourished and less malnourished population is predicted to widen over time.

One interpretation of these results may be that child survival interventions are less efficacious in more malnourished populations and that further progress will be constrained unless general malnutrition is reduced. This interpretation does not seem supportable because it assumes that a biological mechanism underlies the WA x Year interaction term in these models. This assumption is not testable with the present data but it is not consistent with the knowledge that immunizations, oral rehydration, antibiotics, vitamin A supplements and other interventions can be highly efficacious in populations with high rates of general malnutrition. A second and more plausible interpretation (advanced here as an hypothesis) is that countries and periods within countries characterized by high rates of general malnutrition may have lower *coverage* (and/or greater variability in coverage) of child survival interventions *and* higher risk of death among the malnourished, as documented at the individual child level[29]. Thus, gaps in coverage may be more likely and more serious in the more malnourished populations. This interpretation restricts itself to aggregate-level attributes such as coverage, consistent with the aggregate-level unit of analysis at which the interaction is being observed, but also acknowledges the potentiating effect of malnutrition at the child level documented previously. The lack of a significant interaction between WA and Year in the *sub-national* data is consistent with this interpretation, because analyses at that level control for all unmeasured factors that distinguish "provinces" from one another, and coverage of child survival interventions may be one such factor. Thus, one would expect this interaction to become diminished when such factors are controlled. This interpretation could be tested through more detailed analysis of the sub-national (DHS) data which contain some information on health service coverage.

If this interpretation is correct, there are several policy implications. First, it suggests that the policy shift toward selective child survival interventions in the 1980's may have been responsible for saving many lives and this impact could be improved by intensifying efforts to ensure access to child survival interventions among the more malnourished populations. This

[29] D.L. Pelletier, E.A. Frongillo and J.P. Habicht, "Epidemiologic evidence for a potentiating effect of malnutrition on child mortality," Am J Publ Hlth 83:1130-33 (1993).

includes entire countries and regions in some cases, notably Sub-Saharan Africa, as well as the more marginal or malnourished provinces and communities within low-to- medium mortality countries.

Second, child survival could be accelerated by reducing general malnutrition. The present study suggests that reducing the prevalence of low weight-for-age by 5 percentage points by 2005 could reduce child mortality by about 30% and under-5 mortality by 13% (Appendix 3). These reductions are beyond those predicted from the current secular trend and its associated socioeconomic improvements and selective health/nutrition interventions. As these percentages are independent of the absolute mortality rate, the numbers of lives saved would be greater in higher mortality populations. This represents a second rationale for targeting the more poorest and least well-served marginal populations and is a powerful argument for addressing general malnutrition in addition to selective health and nutrition interventions.

Third, as countries reach medium-to-low mortality rates, reductions in general malnutrition become progressively *more* important to achieve further reductions in mortality. This may reflect persistent inequities in access to health services, which are found disproportionately among the malnourished, combined with the potentiating effects of malnutrition operating on those with limited access.

Finally, if the policy goals extend beyond child survival to include other aspects of human development, economic development and social equity, improvements in general malnutrition take on even greater importance.

APPENDIX 1

Countries included in the national and sub-national data sets. The number following each country number of surveys (national level) and the number of surveys and provinces per country (sub-national level).

NATIONAL DATA SET

Sub-Saharan Africa:	Congo (Democratic Republic) (2), Ethiopia (2), Ghana (2), Ivory Coast (2), Kenya (2), Lesotho (3), Madagascar (4), Malawi (3), Mali (2), Mauritanien (2), Mauritius (2), Niger (2), Nigeria (2), Rwanda (2), Senegal (4), Sierra Leone (2) Tanzania (United R) (2), Togo (3), Uganda(2), Zambia (2), Zimbabwe (2)
Central /South America and Caribbean:	Bolivia (8), Brazil (3), Chile (9), Colombia (5), Costa Rica (7), Dominican Republic (3), El Salvador (2), Guatemala (2), Haiti (3), Honduras (4), Jamaica (5), Mexico (3), Nicaragua (4), Panama (2), Peru (4), Trinidad and Tobago (2), Uruguay (2), Venezuela (7)
South East Asia, South Asia, West Asia and North Africa:	Indonesia (2), Laos (2), Malaysia (5), Myanmar (2), Philippines (6), Thailand (2), Viet Nam (3), Bangladesh (5), India (4), Nepal (2), Sri Lanka(4), Egypt (5), Jordan (3), Morocco (2), Oman (2), Pakistan (4), Syrian Arab (2), Tunisia (3), Turkey (2), Yemen (3)

SUB-NATIONAL DATA SET

Sub-Saharan Africa:	Burkina Faso (5/2), Cameroon (5/2), Ghana (8)/3), Kenya (7/2), Madagascar (5/2), Niger (6/2), Senegal (4/2), Tanzania (United R) (6/2), Togo (5/2), Zambia (6/2)
Central/South America and Caribbean:	Bolivia (3/2), Columbia (5/2), Dominican Republic (6/2), Guatemala (6/3), Peru (4/2)
Southeast Asia, South Asia, West Asia and North Africa:	Egypt (3/3), Morocco (7/2), Turkey (4/2), Bangladesh (4/2)

APPENDIX 2

Tables A1, A2, & A3

Table A1: Results of Mixed Model Regression, Natural Log of Under-5 Mortality at National Level (longitudinal)[30]

		Model				
Variables	**Region**	**1**	**2**	**3**	**4**	**5**
Intercept		5.327	3.627	4.8453	4.6578	5.079
Year (centered)		- 0.0399***		- 0.0348***	-0.0356***	-0.0492 p=.0001
WA			0.0313***	0.0151***	0.0134***	0.00155 p=.830
Region	SSAfrica SCAmerica Asia/NAfr				0.8226 -0.1201 0 ***	0.1973 0.2755 0 p=.822
Year x Region	SSAfrica SCAmerica Asia/NAfr					0.0219 -0.0191 0 p=.104
Region x WA	SSAfrica SCAmerica Asia/NAfr					-0.00115 -0.03065 0 p=.059
Year x WA						.000382 p=.010
Year x Region x WA						.000042 .001247 0 p=.040
Variance		0.5762	0.3794	0.4422	0.2823	0.3077
Residual		0.0363	0.0789	0.0362	0.0358	0.0275
N		182	182	182	182	182

[30] Values are regression coefficients unless as noted. Overall term (F-test): *** p<.01 **p<.05 *p<.10 Intercept only model Variance= 0.5304, residual=. 0.1013

Table A2: Results of Mixed Model Regression, Natural Log of Under-5 Mortality at Sub-national Level (longitudinal)[31]

Variables	**Region**	**Model**				
		1	**2**	**3**	**4**	**5**
Intercept		4.959	4.223	4.5213	4.3208	4.4778
Year		-0.0301***		-0.0284***	-0.0286***	-0.0436 ***
WA			0.0225***	0.0188***	0.0177***	0.00153 ***
Region	SSAfrica SCAmerica Asia/NAfr				.4669 -0.0895 0 ***	.3123 -0.1553 0 **
Year x Region	SSAfrica SCAmerica Asia/NAfr					0.0230 -0.0065 0 ***
Region x WA	SSAfrica SCAmerica Asia/NAfr					
Year x WA						
Year x Region x WA						
Country Variance		0.2335	0.1273	0.1336	0.0735	0.0732
Province Variance		0.0685	0.0317	0.0425	0.0436	0.0469
Residual		0.0219	0.0365	0.0191	0.0189	0.0171
N		226	226	226	226	226

[31] Values are regression coefficients unless as noted. Overall term (F-test): *** p<.01 **p<.05 *p<.10 Intercept only model Variance= 0.3101, residual= 0..0537

Table A3: Predicted Values of Under-5 Mortality for Selected Years and Malnutrition Prevalences, by Region. (from Model 5, Table A1)

Under-5 Mortality				
Region	**Year**	**WA=10**[32]	**WA=30**	**WA Rate** [33]
Africa	1980	139	169	**0.9**
	1995	99	137	**1.6**
	Year Rate [34]	**-2.3**	**-1.0**	**-**
C/S America	1980	69	65	**0.5%**
	1995	31	48	**2.0%**
	Year Rate	**-5.4%**	**-2.0%**	**-**
Asia/ N Africa	1980	79	92	**0.7**
	1995	40	52	**1.3**
	Year Rate	**-4.6%**	**-3.8**	**-**

[32] Values are child deaths per 1000 children per year.
[33] Values are the compounded rate of change in mortality as a function of malnutrition (WA Rate).
[34] Values are the compounded rate of change in mortality as a function of year (Year Rate).

APPENDIX 3

Methodology for Calculating Lives Saved by Nutritional Improvement

The parameter estimates from this study can be used to estimate the number of lives saved by improvements in the general malnutrition of populations.[35] This was not possible based on earlier work[36] because analysts would need to know the "baseline mortality" (the mortality rate among the well-nourished) in a given population, and such knowledge usually does not exist. In addition, the previous work was based on prospective cohort studies utilizing anthropometric measurements at a single point in time, as opposed to the dynamic relationships examined in the present study.

The methodology to estimate lives saved by nutritional improvement based on the present study requires two pieces of information: 1) an estimate of the child (or under-5) mortality rate at the beginning of the period; and 2) an estimate of the compounded rate of change in mortality for a given reduction in the prevalence of malnutrition (with prevalence defined in relation to the –2 Z-score cut-off point).

The estimate of initial mortality rate (M1) should be based on a population-based survey or census in an appropriate geographic area and as close as possible in time to the period under consideration. Thus, national level estimates should be used for calculations at the national level, provincial or regional estimates at sub-national levels, and (where possible) district or community level estimates for calculations at those levels. Provisional estimates for a district or community might be obtained by using estimates from higher administrative levels, if the assumption can safely be made that these are representative of the project area. If uncertainty exists about this assumption, the calculations below might be performed for a high-end and a low-end estimate of the initial mortality, and the lives saved can thereby be reported as a range rather than a single point estimate.

An estimate of the compounded rate of change in mortality in a given year (R) as a function of the change in the prevalence of low weight-for-age (dWA) was derived by generating a series of predicted values from a regression model using the national level data. Although the three-way interaction models shown in Table 3 (for child mortality) and Table A1 (for Under-5 mortality) are the best-performing models in terms of the amount of variance in mortality they explain, these are not the most relevant criteria for deriving a parameter estimate (R) for making projections based on changes in WA. For present purposes the more relevant criteria relate to precision of the parameter estimate (R) and performance in predicting values outside the range of the data. As shown in Table A4 the model chosen for this purpose includes terms for year, $year^2$, WA, region and the interaction terms for $year^2$ x region and $year^2$ x WA. The use of this model is based on the assumption that the region-specific coefficients for WA shown in Tables 3 and A1 are not estimated with sufficient precision for use in making projections. In addition, the interaction terms with $year^2$ help model the highly significant region-specific variations in the pace and shape of the secular trend in mortality and the highly significant increase in the

[35] Note that this methodology also can be applied in a straightforward manner to estimate the number of lives lost due to an increase in the prevalence of malnutrition.

[36] D.L. Pelletier, E.A. Frongillo, D.G. Schroeder, and J.P. Habicht, "A methodology for estimating the contribution of malnutrition to child mortality in developing countries," J Nutr 124:2106S-2122S (1994).

coefficient for WA over time. Finally, it is noteworthy that this model performs nearly as well as the three-way interaction models shown in Tables 3 and A1 in terms of the variance explained, but requires fewer degrees of freedom.

Table A4: Results of Simplified Mixed Model Regression Using the Natural Log of Child and Under-5 Mortality at the National Level (longitudinal)[37, 38]

	Region	Child Mortality	Under-5 Mortality
Intercept		2.6697***	5.0010***
Year (centered)		-0.0748***	-0.0295***
$Year^2$		-0.0004	-0.00065
WA prev		0.0059	0.0023
Region	SSAfrica	0.90288	0.42348
	SCAmerica	-0.2294	-0.2351
	Asia/NAfr	0 ***	0 ***
$Year^2$ x Region	SSAfrica	0.0008	0.0006
	SCAmerica	0.0002	0.00005
	Asia/NAfr	0 ***	0 **
$Year^2$ x WA prev		0.00003***	0.000015***
Country Variance		0.539	0.300
Residual		0.164	0.028
n		188	182

Using this model, R was derived from the predicted mortality (M1) at one level of malnutrition in relation to the predicted mortality (M2) at a different level of malnutrition, using the equation:

$M2 = M1 \times e^{R*dWA}$ (1)

Such that:

$R = (\ln M2 - \ln M1) / dWA$ (2)

The estimate of R derived in this fashion varies by year because of the highly significant interaction between dWA and Year revealed in those models. Thus, for child mortality R is estimated to be 0.012 in 1980, 0.032 in 1995, 0.041 in 2000 and 0.053 in 2005. For under-5 mortality R is 0.50 in 1980, 0.015 in 1995, 0.020 in 2000 and 0.025 in 2005. [39]

[37] Values are regression coefficients unless as noted. Overall term (F-test): *** p<.01 **p<.05 *p<.10

[38] The linear (Year) component also was interacted with Region and WA prev, by itself as well as in combination with the quadratic component shown here. These models produce virtually identical results to those shown here.

[39] When these rate coefficients, which appear in the exponent of equation 1, are expressed in compounded percentage terms, the corresponding estimates for child mortality are 1.2% 3.2%, 4.1% and 5.3%, and the corresponding estimates for under-5 mortality are 0.5%, 1.5%, 2.0% and 2.5%. These represent the percent decrease in mortality for each percentage point decrease in the prevalence of malnutrition.

Analysts can use these rate coefficients to estimate the mortality rate (M2) at the end of an intervention period by substituting the appropriate coefficient and the observed change in malnutrition into equation 1. To simplify this task, the values for the expression e^{R*dWA} are shown in Table A5 below and the values for M2 are shown for a range of initial mortality rates (M1) and reductions in malnutrition prevalence (dWA). Linear interpolation can be used for other combinations within these ranges. This table is based on the rate coefficients for 2005 to encourage the use of a common set of parameters by future analysts in different settings. Given the anticipated policy and programmatic uses of these estimates, and the other sources of error described below, the use of common coefficients and methods is more important than the marginal increase in apparent precision that might be gained by using year-specific rate coefficients. However, retrospective analyses extending before 2000 might well be better-served using rate coefficients appropriate for the period under consideration.

Table A5: Predicted Mortality (M2)[40] in Relation to Initial Mortality (M1) and Change in Malnutrition in a Population (dWA)[41]

Percentage Point Decrease in Malnutrition (dWA)						
Initial Child Mortality (M1)	**2**	**4**	**6**	**8**	**10**	**15**
5	4.5	4.1	3.7	3.3	3.0	2.3
10	9.0	8.1	7.3	6.6	6.0	4.6
15	13.5	12.2	11.0	9.9	9.0	6.9
20	18.0	16.3	14.7	13.2	12.0	9.2
25	22.5	20.3	18.4	16.6	15.0	11.5
30	27.0	24.4	22.0	19.9	19.0	13.8
35	31.4	28.5	25.7	23.2	21.0	16.2
40	36.1	32.5	29.4	26.5	24.0	18.5
Initial Under-5 Mortality (M1)						
20	19.0	18.1	17.2	16.4	15.6	13.7
40	38.0	36.2	34.4	32.7	31.1	27.5
60	57.0	54.2	51.6	49.1	46.7	41.2
80	76.0	72.4	68.8	65.5	62.3	54.9
100	95.0	90.4	86.0	81.8	77.8	68.6
140	133.0	126.6	120.4	114.6	108.9	96.1
180	171.0	162.7	154.8	147.3	140.1	123.5
220	209.0	198.9	189.2	180.0	171.2	151.0

[40] Tabled values are M2. M1 and M2 are in deaths per 1000 children or Under-5's per year.
[41] All estimates are based on R= 0.052 for child mortality and R= 0.025 for Under-5 mortality, which apply to the year 2005. Estimates for earlier years can be derived using the methods described in this Appendix 3.

Finally, the number of lives saved by nutritional improvement (L) in a project area with n children or under-5's is calculated as:

$$L = (n/1000) \times (M1-M2) \qquad (3)$$

Note that L as calculated in equation 3 refers to the number of lives saved by nutritional improvement for each year in which the change in the prevalence of malnutrition is at the level specified in equations 1 and 2. Thus, if the prevalence decreased in a gradual manner over a five year period in a project area, the total lives saved during the entire period would be the sum of the lives saved each year.

To illustrate the use of these methods, if the initial child mortality (M1) in a project area was 40 per 1000, and malnutrition decreased by 4 percentage points (dWA), then the new mortality estimate (M2) as provided in the table is 32.5 per 1000. If the project area contains 5000 children, then the lives saved by nutritional improvement in that year is given by:

$L = (n/1000) \times (M1-M2) = 5000/1000 \times (40-32.5) = 37$ children.

Users should be aware that the estimates derived from this method have some inherent uncertainties from several sources. These include: 1) possible errors in estimating the initial mortality rate in the project area; 2) uncertainties about the "true" value of the malnutrition rate coefficient (R); an approximation for this uncertainty is provided by the additive (non-interactive) model where the WA prev coefficient is 0.0224 and the standard error is 30% of this value (0.0067). For under-5 mortality the corresponding coefficient is 0.0094, the standard error is 40% of this value (0.0037); and 3) variation in the mix of health and nutrition problems and interventions across project settings and into the future, which may exceed that represented by the mix of countries included in this study. For these reasons, analysts may wish to report their results in terms of a range rather than the single point estimates provided in the table below.

A practical rule of thumb for reporting a range of estimates is to perform the calculations described above using a lower-end and an upper-end bound for R based on the standard errors reported above. For child mortality the lower bound of R would be 0.036 (=0.052 x 0.7) and the upper bound of R would be 0.068 (= 0.052 x 1.3). For under-5 mortality the lower bound of R is 0.015 (=. 0025 x 0.6) and the upper bound of R is 0.035 (= 0.025 x 1.4). These values would be substituted into equation 1 above, along with the observed change in malnutrition prevalence (dWA) to estimate M2.

It should be emphasized that the methodology described here generates estimates of lives saved by nutritional improvement *net* of the changes attributable to the secular decline in mortality underway in most developing countries. As such, the estimate of M2 generated by equation 1 represents the marginal change attributable to nutritional improvement and may differ from the actual mortality rate as measured directly in the project area. The latter rate would reflect the combined effects of secular decline and malnutrition improvement.

Finally, it bears reiterating that this methodology provides conservative estimates of the number of lives saved by nutritional improvement because the statistical models upon which it is based are only capable of estimating the *statistically independent* effect of nutritional improvement on mortality decline (independent of the secular trend). It is likely that some portion of the decline attributed to the secular trend in this study should be attributed to changes in malnutrition.

Figure 1: Trends in child mortality, 1975-1995. Values were predicted on a region-specific basis by regressing child mortality (deaths per 1000 children per year) on year and year^2.

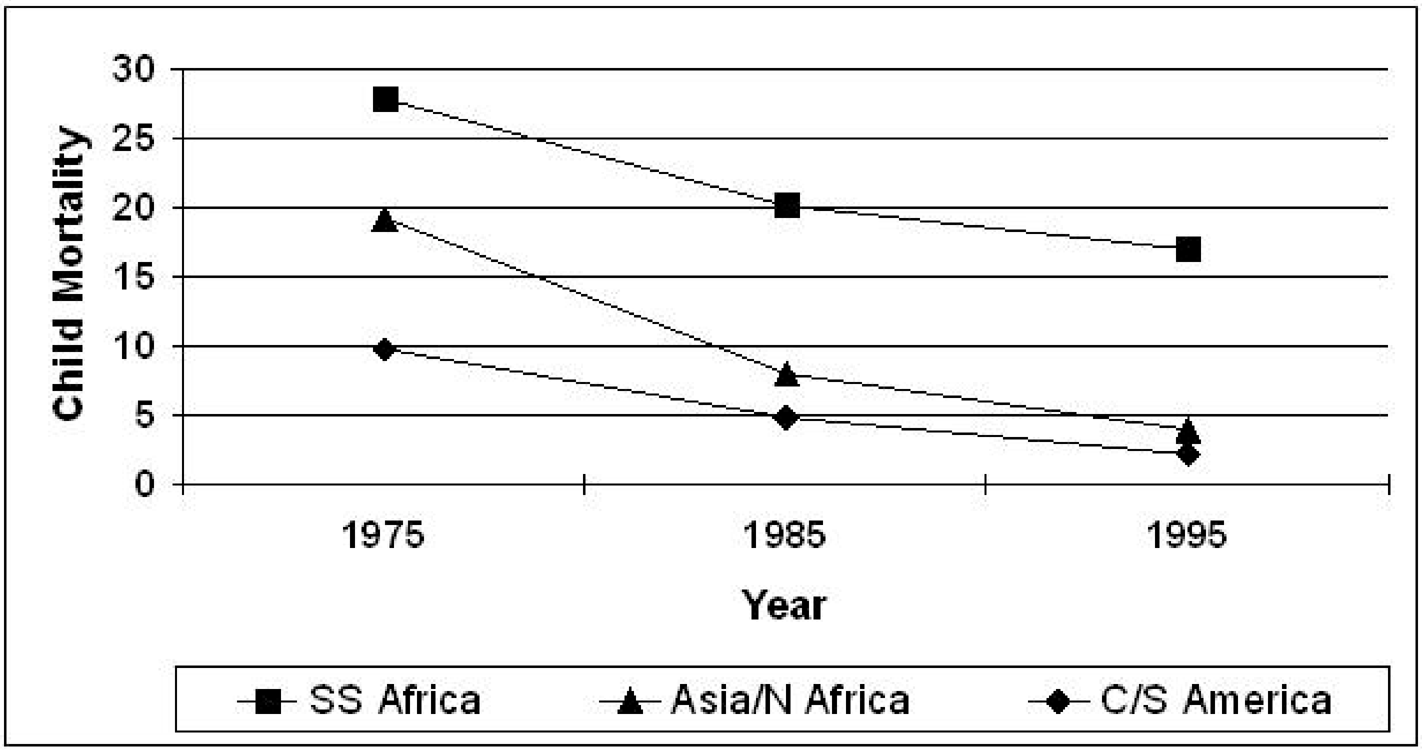

Figure 2: Trends in Under-5 mortality, 1975-1995. Values were predicted on a region-specific basis by regressing Under-5 mortality (deaths per 1000 livebirths) on year and $year^2$.

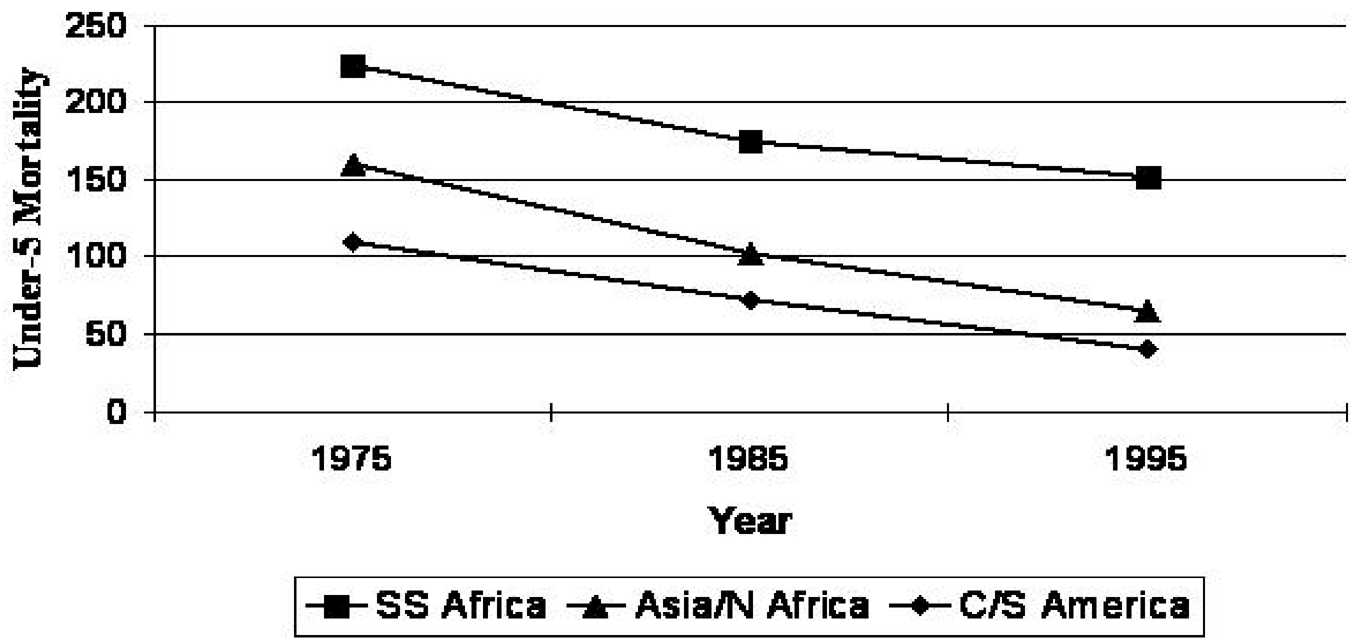

Figure 3: Trends in child malnutrition, 1975-1995. Values were predicted on a region-specific basis by regressing child malnutrition (percent of children less than -2 Z-scores of weight-for-age) on year and $year^2$.

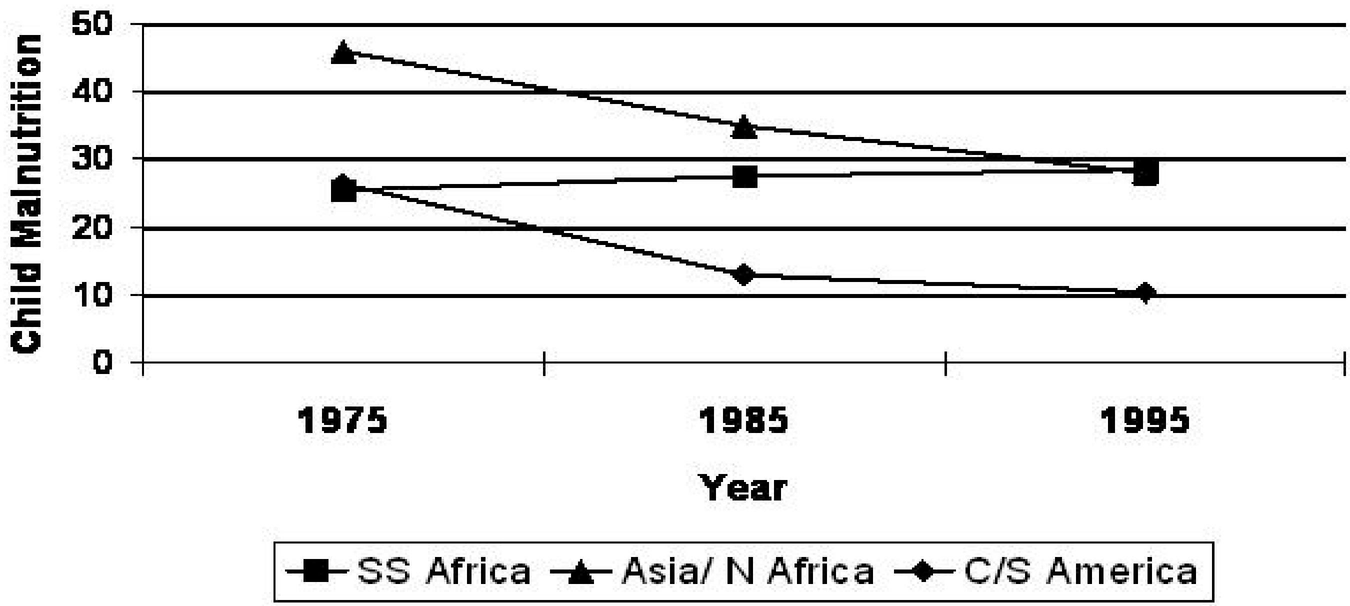

Figure 4: Child Mortality in Relation to Year Malnutrition: Sub-Saharan Africa. Predicted Values are predicted from Model 8, Table 3. Child mortality refers to deaths per 1000 children per year. Malnutrition refers to percent of children less than -2 Z-scores for Weight-for-age.

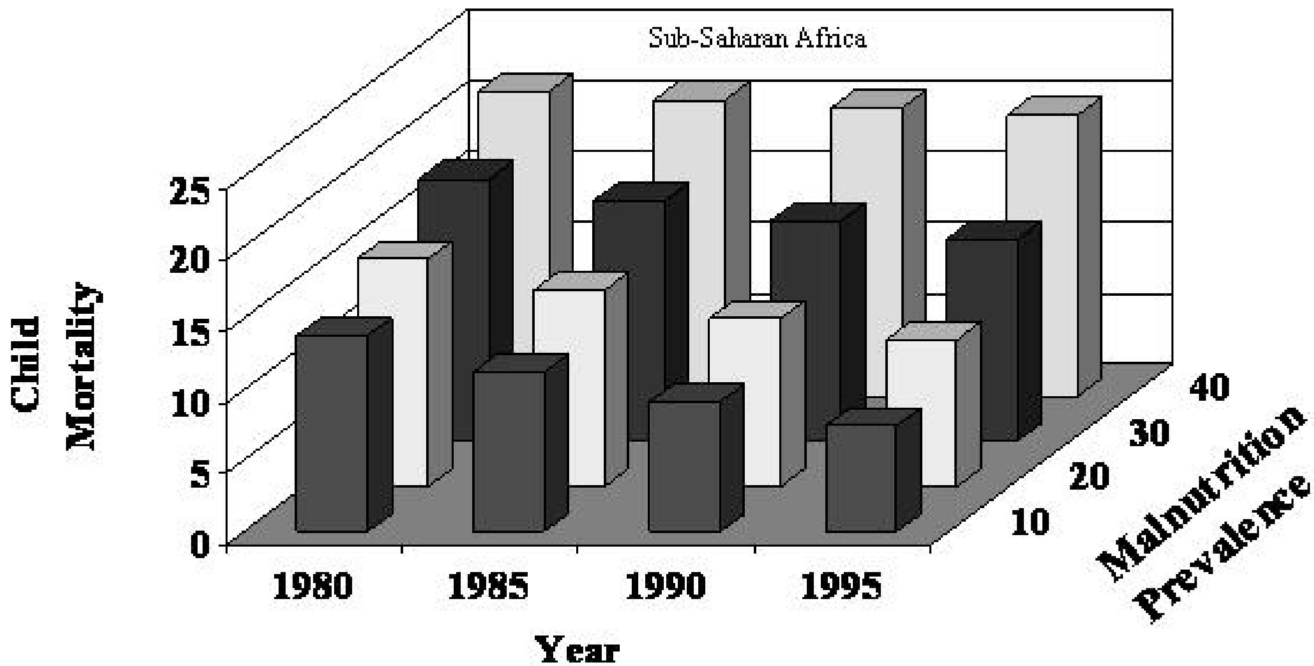

Figure 5: Child Mortality in Relation to Year Malnutrition: Central and South America and the Caribbean. Values are predicted from Model 8, Table 3. Child mortality refers to deaths per 1000 children per year. Malnutrition refers to percent of children less than -2 Z-scores for Weight-for-age.

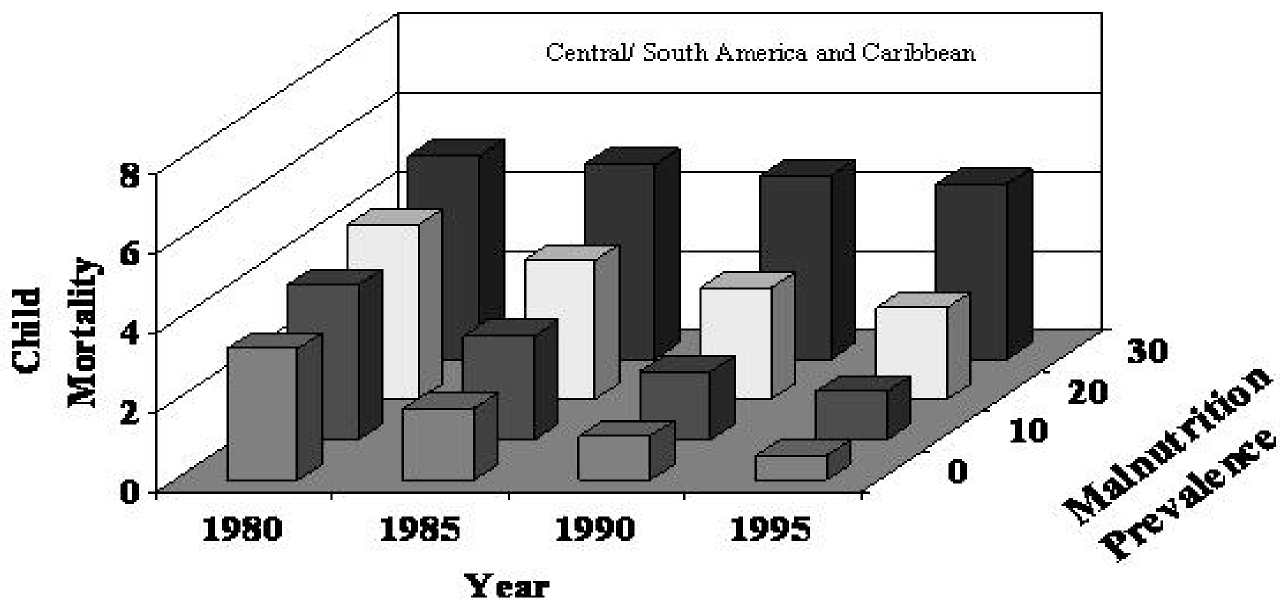

Figure 6: Child Mortality in Relation to Year Malnutrition: Asia and North Africa. Values are predicted from Model 8, Table 3. Child mortality refers to deaths per 1000 children per year. Malnutrition refers to percent of children less than -2 Z-scores for Weight-for-age.